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Empowering Kanban through TPS-Principles - An Empirical Analysis of the Toyota Production System

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Abstract

The purpose of this paper is the empirical investigation of the Toyota Production System in order to test existing relationships as they are proposed in theory. The underlying model consists of seven factors reflecting the key practices of the Toyota Production System. Using data from 188 manufacturing plants participating in the High Performance Manufacturing research project, the model's measurement characteristics were validated through confirmatory factor analysis. Path analysis of the model showed that the majority of the relationships can be confirmed. Furthermore, a comparison of mean analysis based on a conducted cluster analysis indicates that plants with a higher implementation degree of the practices of the Toyota Production System show also a higher perceived performance in terms of the key criteria of production, i.e., time, cost, quality, and flexibility.

Keywords Toyota Production System, just-in-time production, empirical analysis, performance

INTRODUCTION

The Toyota Production System (TPS) can be regarded as the most popular production concept (Black, 2007). Its ground-breaking approach to implement a lean production philosophy on the shop-floor of industrial companies has revolutionized the perspective of manufacturing. Many other automotive companies adopted the practices of the TPS such as Kanban and created an equivalent production system, e.g. the HPS at the Hyundai Motor Company (Lee and Jo, 2007). The Toyota Production System bases upon the philosophy of waste elimination, which results in lean and rational production processes (Monden, 1983).

Although many times the Toyota Production System is equated with just-in-time production, the very basic concept is the “reduction of cost through the elimination of waste” (Sugimori et al., 1977). This fact is also stressed by Shingo (1989), who states the meaning of its primary purpose: “It’s a system for the absolute elimination of waste.” Using the concepts of the Toyota Production System, companies are able to eliminate waste, therefore produce efficiently and gaining a competitive advantage, which is stressed by Spear and Bowen (1999): “The Toyota Production System has long been hailed as the source of Toyota’s outstanding performance as a manufacturer.”

Considerable research has been done on the Toyota Production System, especially on the contribution of the TPS practices to manufacturing performance. One of the main drivers for the superior performance is the utilization of the just-in-time philosophy by the thorough implementation of Kanban (Ohno, 1988). However, there is limited research on the interdependence of the underlying TPS practices and how they affect Kanban and which TPS practices are necessary for a successful Kanban implementation. The paper wants to close this gap by showing that Kanban enforces its

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4 full potential, if Kanban is embedded in a supportive infrastructure, which is
5 represented by a three layer model. In this model Kanban forms the practice of the main
6 layer, which bases upon a supportive layer of practices (factory layout, setup times and
7 quality). These supporting practices are empowered by a layer of primary practices
8 (multi skilled and trained workers), which is the key driver for a thorough Kanban
9 implementation.
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18 The paper is organized as follows. Firstly, we review the relevant literature in
19 terms of the practices of the Toyota Production System, which constitute the three
20 layers of the Kanban model as a foundation of the empirical analysis. Secondly, the
21 main hypotheses for the empirical analysis are developed. Finally, we present the
22 research design and key variables, before concluding with the analysis of the study and
23 summary results.
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35 **LITERATURE REVIEW**

36 *Basic approaches of the Toyota Production System*

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38 The foundation of the lean philosophy is that all forms of waste have to be eliminated,
39 as waste is defined as any activity which does not add value in the eyes of the customer.
40 Some authors report a percentage of waste in a traditional production system of about
41 90 percent (Shingo, 1989; Stalk and Hout, 1990). Ohno identifies 7 sources of waste,
42 which are waste of overproduction, waiting, transporting, over-processing, inventories,
43 moving, and defective parts and products (Ohno, 1988). Additionally, the waste of not
44 making use of peoples' potential is mentioned. The following practices within the
45 Toyota Production System strive to eliminate the sources of waste to ensure an efficient
46 and lean production system.
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There are two central approaches of the Toyota Production System: just-in-time and “respect for human” system. Just-in-time is achieved through the implementation of numerous, well-known practices such as Kanban, short setup times, multi-skilled workers, etc. However, just-in-time production is just a vehicle to reach the overall goal of the total elimination of waste and, thereby, to implement lean production. Furthermore, Shingo (1989) even points out that “the Toyota Production System is so powerful that it could squeeze water from a dry towel”, which expresses the ability of TPS to eliminate waste and gain productivity in production.

The second central approach of the Toyota Production System is the “respect-for-human” system (Sugimori et al., 1977). All workers physical movements should add value to the product, otherwise they are considered waste. Since the workers take care of many quality problems themselves, they enjoy much broader responsibilities and authority, e.g., every worker at Toyota has the privilege, but also the duty to stop the assembly line if a problem occurs.

Practices of the Toyota Production System

Following Ohno (1988), the first aspect of the Toyota Production System is “putting a *flow* into the manufacturing process”. In order to realize this flow, the just-in-time production concept must be regarded as the most critical aspect (Pegels, 1984). In a just-in-time framework, the production of parts, components, etc. has to occur exactly just-in-time, i.e., not any earlier or any later. In literature there appears to be an agreement about the advantages of just-in-time production, which consist of low inventories and scrap costs, better quality, faster response to engineering changes and higher productivity (Goyal and Deshmukh, 1992).

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Contrary to Sakakibara et al. (1997), who see just-in-time as an overall organizational phenomenon, this paper concentrates on the issues that are directly linked to shop-floor operations such as setup, maintenance, etc. How such a just-in-time approach can be accomplished with respect to the production control of a manufacturing plant, can be answered with the production concept of Kanban (see for a discussion of the TPS and Kanban in the academic literature New, 2007). For Toyota, pull systems, respectively Kanban represent the ideal state of just-in-time manufacturing, because it provides the customer with what, when and the amount he or she wants (Liker, 2004). With the inherent flexibility of the Kanban system, Toyota sustains its just-in-time manufacturing (Monden, 1981).

Shingo (1989) describes the basic idea of Kanban by the following analogy: “Some people imagine that Toyota has put on a smart new set of clothes, the Kanban system, so they go out and purchase the same outfit and try it on. They quickly discover that they are much too fat to wear it!” Accordingly, manufacturers must eliminate waste and make fundamental improvements in their production system before a technique such as Kanban can work efficiently. Shingo concludes that the Toyota Production System is 80 percent waste elimination, 15 percent production system, and only 5 percent Kanban (Shingo, 1989).

Following the just-in-time concept, production is strictly triggered by Kanban cards so that no early or late production is allowed. This simple steering mechanism does not need a complex and therefore costly computer system for support and avoids the bureaucratic procedures of push system concepts (Pegels, 1984). This decentralized production control system allows the parts and components to flow smoothly through a lean production facility.

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The pull principle as basic idea of Kanban is often illustrated by the example of a supermarket (Shingo, 1989): Supermarket customers buy what they want, when they need it. Since they take away what they need, a gap in the shelves occurs. This gap will be refilled again. The supermarket system was adopted in the machine shop at Toyota around 1953 (Ohno, 1988). Also in terms of Kanban, Ohno refers to the meaning of just-in-time: “If parts arrive anytime prior to their need – not at the precise time needed – waste cannot be eliminated. By using Kanban, waste of overproduction is completely prevented” (Ohno, 1988).

However, if applied, Kanban reduces cost by decreasing inventories and increases on-time performance by producing parts and components with short cycle times. Accomplishing just-in-time production by using Kanban is only one step. In order to implement Kanban effectively it has to be supported by other TPS practices. This aspect is supported by Liker, who states that the TPS practices condition each other. The TPS is not a toolbox, where a company can pick the instruments that appear to be useful, but represents an approach that has to apply all TPS principles as a system in order to be effective (Liker, 2004). These practices constitute a supportive and a primary layer enabling Kanban to work effectively. Furthermore, it is important to note that success necessitates the integration of the TPS practices and definitely not highly selective use of just one practice (Towill, 2007). A successfully working Kanban system demands an integrated infrastructure of supporting practices making Kanban more a result than an enabler of thoroughly implemented TPS practices. The highly integrated nature of Kanban can be seen as one reason why Kanban might be utilized only to a low extend. Hence, the supportive layer will be described in the following.

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5 A consequence of a smooth production flow is the production in small lots
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7 (Sekine, 1992). A lean production system strives for the ideal lot size of one. But small
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9 lots lead to many setups, which would disrupt a smooth production flow. This fact is
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11 stressed by Sugimori et al. (1977), who state: "...each process can produce only one
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13 piece, can convey it one at a time, ..., have only one piece in stock...". Goyal and
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15 Deshmukh (1992) strengthen this by even saying that "JIT ultimately aims at unit lot
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17 sizes and consequently aims at minimizing the setup time". Therefore, short setup times
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19 are a prerequisite.
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24 An approach for drastically reducing setup times is introduced by Shingo
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26 commonly referred to as SMED (Shingo, 1985; Shingo, 1989; for a critical evaluation
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28 see McIntosh et al., 2000). With SMED setups are analyzed in terms of their potential to
29
30 reduce the needed setup time. In order to shorten the time that a machine has to shut
31
32 down, setup process steps are differentiated into two classes: internal and external.
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34 Internal setup steps are those that can only be performed while the machine is standing
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36 still, whereas external setup steps can be done while the machine is still running. SMED
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38 tries to convert internal in external steps. By SMED, setup times have been shortened
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40 dramatically, e.g., Toyota has shortened the time for a setup of a press from more than
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42 three hours to the single-minute-range (Pegels, 1984). On average, the reductions by
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44 SMED techniques are around 80 to 95 percent (Shingo, 1989).
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51 Kanban requires a reliable production system because the negative consequences
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53 of machine breakdowns and production disruptions cannot be compensated anymore. A
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55 reactive maintenance strategy is not appropriate any longer, because a so called fire-
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57 fighting strategy leads to many unexpected machine breakdowns, since machines solely
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59 receive maintenance in the case of a breakdown and not before a malfunction occurs. In
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4 a lean environment, the occurrence of breakdowns cannot be accepted anymore and
5 must be eliminated. The main purpose of preventive maintenance is to maximize overall
6 equipment effectiveness by eliminating unexpected machine breakdowns (Nakajima,
7 1988). This is achieved by a scheduled maintenance programme or conditioned-based
8 maintenance.

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17 To enable preventive maintenance, other supportive approaches such as
18 autonomous maintenance or training of machine operators are necessary in order to
19 make a preventive maintenance system work effectively (Thun, 2006, Goto, 1989a).
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23 Especially training of machine operators is a necessity for the successful
24 implementation of Total Productive Maintenance. Furthermore, the overall equipment
25 effectiveness (Dal et al., 2000; Ljungberg, 1998) can be increased by maintenance
26 prevention (Goto, 1989a), i.e., machines are improved during the development process.
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33 In this paper, we focus on preventive maintenance as basic idea of Total Productive
34 Maintenance.

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39 The effectiveness of the Kanban system is supported by a production process
40 structure that enables a constant and smooth flow. The layout, how the production
41 process can be organized is illustrated with the following statement by Ohno (1988): “In
42 the past, lathes were located in the lathe department, and milling machines in the
43 milling area. Now, we place a lathe, a milling machine, and a drilling machine in the
44 actual sequence of the manufacturing processing. This way, instead of having one
45 worker per machine, one worker oversees many machines or, more accurately, *one*
46 *worker operates many processes.*” At Toyota, such a system is called multi-process
47 operation system. By a layout, which considers the production flow, productivity can be
48 improved significantly (Wemmerlöv and Hyer, 1989; Wemmerlöv and Johnson, 1997;
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4 Hyer and Wemmerlöv, 2002). However, workers must be multi-skilled in order to fulfil
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6 the requirements of such a layout in terms of different operating tasks (Huber and Hyer,
7
8 1985). In a layout for smooth production flow, the system has to change from “one
9
10 operator, one machine” to a system of “one operator, many machines in different
11
12 processes” (Ohno, 1988).
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17 In the Toyota Production System, all errors are sources of waste. Everyone in
18
19 operations must beware of the meaning of quality. Goyal and Deshmukh (1992) stress
20
21 the importance of quality as the “critical element for JIT’s success”. The attitude
22
23 towards quality must be changed in a way that quality has to be produced originally, not
24
25 checked afterwards, which is known as quality at the source. The production system
26
27 should guarantee a frictionless operation. This way, the production system strives for
28
29 zero defects, so that an undisturbed material flow through the production processes is
30
31 possible. In order to produce quality at the source, techniques such as statistical process
32
33 control are used. For the monitoring of the process quality, workers must be trained.
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35 With a high process quality level, shorter lead times and less safety stock can be
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37 achieved.
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44 The primary layer consists of two practices, i.e., multi-skilling and training. As
45
46 setting up of the production flow is of primary interest, the Toyota Production System
47
48 strives to achieve a multi-process operating system. For a machine operator on the
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50 production line, who works in a multi-process operation system, this requires the
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52 operator to become multi-skilled (Ohno, 1988). Accordingly, multi-skilled workers are
53
54 a critical issue for a layout in which a worker has to operate at several different
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56 machines. Besides layout, multi-skilled workers are important for the reduction of setup
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58 times (Jindia and Lerman, 1995). They have to be able to accomplish the actions
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4 required for minimized change over times that are part of the implementation of a
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6 SMED system.
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9 The second practice in this layer is the training of machine operators. The
10 importance of training for the functioning of just-in-time production is stressed by
11 Sakakibara et al. (1997): “Training programs ... are important in developing flexible
12 workers ... to facilitate a smooth production flow.” Accordingly, training is one explicit
13 pillar of Total Productive Maintenance. Furthermore, it is necessary to train machine
14 operators in order to enable them to fulfil new tasks, e.g., process related quality control.
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16 An overview of all layers and the particular practices is given in figure 1.
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25 26 27 28 29 *Review of empirical work*

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32 In the literature, a few empirical papers on the Toyota Production System in terms of
33 just-in-time and Kanban exist. The interrelation between just-in-time and quality is
34 investigated by Flynn et al. (1995). Forza (1996) examines the differences between lean
35 plants and traditional plants in terms of the work organization. A comprehensive
36 analysis on just-in-time manufacturing is provided by Sakakibara et al. (1997). They
37 analyze the relationship to the infrastructure and the performance. Nakamura et al.
38 (1998) investigate the adoption of just-in-time manufacturing. They compare U.S.
39 plants and Japanese owned plants. White et al. (1999) investigate the differences of the
40 implementation of just-in-time manufacturing in small and large U.S. companies and
41 the impact on performance. They come to the conclusion that the frequencies of the 10
42 JIT management practices implemented differ between the two groups of manufacturer
43 size. Adler et al. (1999) offer a case study of model changes within Toyota Production
44 System. They analyze the influence of the changeovers on the flexibility and the
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4 efficiency of a Toyota subsidiary in the U.S. Three further case studies are presented by
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6 Lewis (2000), in which he explores the impact of lean production principles on
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8 sustainable competitive advantage of firms. Another case study-based research on the
9
10 Toyota Production System is done by van Driel and Dolfsma (2009). Fullerton and
11
12 McWatters (2001) show performance benefits of JIT and continuous process
13
14 improvement with a survey on 95 JIT-practicing firms in the U.S. An examination of
15
16 the relationship between JIT and the financial performance has been done on 253 US
17
18 manufacturing firms by Fullerton et al. (2003). Ahmad et al. (2003) examine
19
20 empirically the role of infrastructure practices on the effectiveness of JIT practices with
21
22 data based on a study of 110 plants from Japan, US, and Italy. They show that the
23
24 majority of the infrastructure practices moderate the relationship between JIT practices
25
26 and plant competitiveness. Matsui (2007) provides an empirical analysis of the impact
27
28 of just-in-time production on competitive performance using the data of 46 Japanese
29
30 manufacturing companies. Altogether it can be stated that none of the empirical studies
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32 analyze the whole package of Toyota Production System key practices, but just its
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34 singular elements.
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46 **EMPIRICAL ANALYSIS**

47 *The High Performance Manufacturing Project*

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49 The empirical analysis is based on data taken from the research project “High
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51 Performance Manufacturing”. This project is an international cooperation of research
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53 groups from the U.S., Japan, Germany, Sweden, Finland, and South Korea. It is the
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55 follow up to the project “World Class Manufacturing”, which was done in 1997 with the
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57 primary purpose to evaluate critical success factors in operations management (Flynn
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4 et al., 1997; see for the basics of the project Schroeder and Flynn, 2001). High
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6 performance manufacturing describes the ability of a production unit to reach
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8 continuous improvements in the manufacturing area through integration and utilization
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10 of a set of compatible management concepts. The data base contains quantitative and
11
12 qualitative data from plants of the automotive, electronic, and machinery industry.
13
14 Aspects such as technology management, IT-management, quality management, or
15
16 human resource management are analyzed in the manufacturing context. Furthermore,
17
18 the questionnaire comprises multiple items reflecting the techniques of the Toyota
19
20 Production System as they have been discussed in the earlier section so that the data can
21
22 be used to construct measures corresponding to the Toyota Production System.
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30 *Research Methodology*

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32 In order to guarantee a proper translation, the international questionnaire is translated by
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34 Professors of Operations Management into the national language and is then
35
36 retranslated into the original language by a different person. Afterwards, the translations
37
38 are compared in order to identify potential translation problems. The plants are
39
40 randomly selected from a list of plants with at least 100 employees. Data is compiled
41
42 for each plant from 23 respondents from various levels in the plant hierarchy and all
43
44 major functional areas. This procedure gives a transversal image of a plant and helps to
45
46 avoid the key informant bias (Sakakibara et al., 1997). Responses are aggregated for
47
48 each plant into one combined data set and constitute multiple indicators of insight about
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50 manufacturing related areas such as just-in-time, quality, factory layout, setups,
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52 manufacturing strategy, human resources, maintenance, etc.
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5 The survey is collected on a country by country basis, i.e., each research group
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7 collects the data of ca. 30 plants of the three industries automotive, electronics, and
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9 machinery separately in their particular country. The plants are defined at the three-digit
10
11 Standard Industrial Classification (SIC) code level. The industries were chosen as
12
13 examples of industries in transition, whose plants were expected to exhibit a wide range
14
15 of variability in practices and performance (Flynn et al., 1997). The data is then
16
17 aggregated into one final international data base. The data base comprises qualitative
18
19 and quantitative information, whereby the qualitative questions are intermixed in order
20
21 to avoid that scale membership is readily apparent.
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26 The estimations for the items concerning the Toyota Production System are
27
28 predominantly given by the Inventory Manager, Production control manager, and three
29
30 shop floor Supervisors each of which is expected to be the most knowledgeable in
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32 providing the desired information. For the empirical analysis, some plants are excluded
33
34 from the data base due to missing data. The indicators used in this research were
35
36 qualitative ones, measured with Likert-type scales ranging from “strongly disagree” to
37
38 “strongly agree” and reflecting perceptions of managerial personnel about their topics.
39
40 The items concerning the Toyota Production System are used to create factors
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42 presenting a statistical construct for the particular subject matter like it is described in
43
44 the following.
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51 *Development of a three layer Kanban Model*

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53 As the Literature Review reveals, the Toyota Production System consists of multiple
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55 practices that are connected with each other. Figure 1 gives an overview of the supposed
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4 relation. The corresponding hypotheses will be discussed afterwards as a basis for the
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6 empirical analysis:
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10 INSERT FIGURE 1

11
12 Figure 1: Overview of the Model

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14 Any Kanban production system will benefit from the different supportive factors
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16 discussed above, since each of the supportive factors will help to meet defined
17
18 prerequisites or requirements to implement Kanban successfully.
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21
22 Thus, the following hypothesis is stated (note that the hypotheses are stated as
23
24 alternative hypothesis):
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28 H₁1: The factors of the supportive layer (Factory Layout, Setup Times,
29
30 Maintenance, Quality) positively influence the implementation of
31
32 Kanban, the main factor.
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34

35
36 All the techniques of the supportive layer as described above cannot work for
37
38 themselves. They depend on other factors, which can be interpreted as the driving force
39
40 of the Toyota Production System: human resources. The Toyota Production System
41
42 emphasises the “respect-for-human” (Sugimori et al., 1977). Accordingly, a primary
43
44 layer is added to the overall system which consists of two factors: multi-skilled workers
45
46 and the training of workers. These people related factors training and capability to fulfil
47
48 multiple tasks constitutes the primary layer that enables a production system that is
49
50 controlled by a Kanban system. Note, that these two factors will not be absolutely
51
52 independent from each other since both deal with a similar issue. However, in this study
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54 we analyze them separately since both practices show essential differences. The second
55
56 main research hypothesis is stated as follows:
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4 H₁2a: The ability of workers to conduct multiple tasks enables the factors of the
5
6 supportive layer, esp. a cellular layout of the production process and
7
8 reduction of setup times.
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12 H₁2b: The amount of training, given to production workers enables the factors
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14 of the supportive layer, esp. preventive maintenance and assurance of
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16 high quality production.
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20 Combined and properly implemented and executed, the described instruments
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22 can result in sustainable performance improvements. Short setup times lead to small lot
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24 sizes and short lead times, combined with Kanban, result in low inventories and a high
25
26 fill rate. A thorough Quality Management keeps quality problems at a minimum and in
27
28 combination with Total Productive Maintenance, production processes are reliable and
29
30 stable. Kanban as a manufacturing execution system keeps the cost of steering the
31
32 production at a minimum.
33
34

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37 The discussed practices are influencing the key performance metrics of
38
39 production time, cost, quality, and flexibility as mentioned by several authors (Ahmad
40
41 et al. 2003, Groenevelt 1993, Primrose 1992). These competitive factors can be
42
43 measured by different manufacturing performance criteria such as unit cost of
44
45 manufacturing, quality of product conformance, on-time delivery performance, or
46
47 flexibility to change product mix (Ahmad et al. 2003). The Toyota Production System is
48
49 aiming and impacting these metrics and therefore the inner heart of production, which is
50
51 the “competitive weapon” of manufacturing companies (Skinner, 1985 and 1969).
52
53 Accordingly, the question is investigated whether the plants that have implemented the
54
55 Toyota Production System to a higher extend than plants with a low implementation
56
57 degree show also a better performance. This aspect and the two hypothesis discussed
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4 above will be tested empirically in the following based on data collected within the
5
6 High Performance Manufacturing project.
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10 11 12 *Analyses*

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14
15 The conceptual model presented in figure 1 is tested against the sample of the HPM-
16
17 project. A path analytic approach is chosen to test the hypothesis 1 and 2a/b since
18
19 traditional regression analyses ignore interrelations between constructs, which
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21 potentially biases the results by excluding important interdependencies from analysis
22
23 (Asher, 1983; Bollen, 1989). This method decomposes the empirical co-variances
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25 among the measured items and estimates path coefficients that are equivalent to
26
27 standardized regression coefficients in a standard regression model. The further
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29 analysis is following a two-step approach. At first the different concepts, e.g., layout of
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31 production process, degree of multi-skilled workers, are composed, using a
32
33 confirmatory factor analysis. The second step of the analysis estimates the strength of
34
35 relationships between the different factors using a path model.
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41 The seven different factors identified as key principles of the Toyota Production
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43 System represent hypothetical constructs that are reflected in different indicator
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45 variables, i.e., a high indicator value of the usage of Kanban containers for signaling in
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47 production control is a representation of the degree of implementation of a Kanban
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49 system in the production system of a given plant. The factors are of reflective nature;
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51 they are causes of the parameter value of each indicator variable associated with a factor.
52
53 Thus, the value of each indicator is a representation of each of the underlying factors.
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55 Table 1 shows the measurement of the seven factors. The validity of the factor model is
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57 assessed by convergent and discriminant validity. Convergent validity is achieved if
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4 agreement between indicators and the underlying theoretical construct is reached. All
5 factor loadings are significant with $p < 0.01$ and show relatively high factor loadings,
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7 leading to the conclusion that good convergent validity is accomplished by the model.
8
9 Only the primary factor multi-skilling shows only low factor loadings. The
10 measurement of this factor is associated with a higher measurement error than other
11 factors of the model. However, all factor loadings are highly significant. Since the
12 overall model fit also shows good explanation of the empirical data, this factor will not
13 be discarded but further interpretation of model results have to consider the inferior
14 measurement of this construct. To assess construct reliability Cronbach's Alpha is
15 calculated for each factor separately. A commonly accepted threshold value for
16 Cronbach's Alpha is 0.7 (Nunnally, 1978). For newly developed scales a threshold
17 value of 0.6 can be accepted (Sakakibara et al., 1997). The results depicted in table 1
18 show that all factors meet this standard.
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34 35 INSERT TABLE 1

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37 Table1: Confirmatory model of TPS main, supportive and primary factors
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42 Further examination of the Toyota Production System constructs has to assess
43 the assumption that each factor is measuring a distinct empirical construct. A common
44 criteria to assess a construct's discriminant validity are factor correlations. A high
45 correlation between factors would indicate that they are not discriminative (Bagozzi et
46 al., 1991). The results depicted in table 2 show that some factors do correlate, partly on
47 a relatively high level. However, since the factors presented here are part of a common
48 production concept it cannot be expected that the factors do not correlate, since the
49 factors are believed to be supportive in nature. The question is whether the strength of
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4 the correlation can lead to the conclusion that the measurement of a single factor is
5 faulty and therefore has to be discarded if modelled as a single factor. In the literature,
6
7 no commonly accepted threshold values exist, however Bagozzi et al. state that only
8
9 very high factor correlation should lead to the conclusion that discriminant validity has
10
11 not been achieved. As for the model presented here, two factor correlations are rather
12
13 high (Multi-skilling + Training, Maintenance + Training). For these factors a test of
14
15 chi-square differences is conducted to further assess discriminant construct validity. All
16
17 constructs show a statistically significant increase in the overall chi-square value of the
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19 model (19.89 and 22.60). Hence, the empirical data is more accurately captured by a
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21 model that contains both constructs as separate factors.
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28 INSERT TABLE 2

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30 Table 2: Factor correlations
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35 *Overall structural model fit*

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37 The research hypothesis 1 and 2a/b will be tested by a structural model presented in
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39 figure 1. As method for parameter estimation, we used “unweighted least square
40
41 (ULS)”. In general, this method is well suited for data sets in the social sciences since
42
43 ULS parameter estimation does not require multivariate normality of the data.
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47 For the assessment of overall model quality, one common test of model fit is the
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49 chi-square value that is 978.88 with 341 degrees of freedom ($p=0.00$) for the presented
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51 model. However, the chi-square test does not account for model complexity. Therefore,
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53 the chi-square value should be divided by the degrees of freedom (Jöreskog and Sörbom,
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55 1982). This quotient should be equal or less than 2.5 (Homburg and Giering, 1996),
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57 which is not fulfilled by the model showing a value of 2.871 that could be seen as a
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4 weakness of the model. However, the usability of the chi-square test in general is
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6 limited and has been questioned in the literature (Bentler and Bonett, 1980; Bagozzi and
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8 Yi, 1988; Fan et al., 1999). The chi-square test is a test of exact fit between empirical
9
10 data and model data although the theoretical model is only designed as an
11
12 approximation of reality (Cudeck and Browne, 1983). In addition, the chi-square value
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14 is sensitive to sample size effects, leading to the result that with an increasing sample
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16 size the presence of only minor deviations from the empirical covariance matrix lead to
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18 a rejection of the theoretical model (Jöreskog and Sörbom, 1982; Bearden et al., 1982).
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24 A more appropriate measure is the share of empirical variance that is captured
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26 by the model, here, goodness of fit indices (GFI) is considered. It is commonly accepted
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28 that the GFI and the adjusted GFI (AGFI) should exceed 0.90. This criterion is matched
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30 by the model presented here (GFI = 0.95, AGFI = 0.94). Further measures to assess
31
32 overall model quality are the root mean square error of approximation (RMSEA) which
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34 should not exceed 0.10, the root mean residual (RMR<0.05) and the comparative fit
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36 index (CFI>0.90). The RMSEA value is closely matched by the model (0.09), also the
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38 CFI (0.97) indicated a reasonable fit of the model. Only the RMR (0.084) is slightly
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40 above the threshold value. Altogether the analysis of the overall model fit shows
41
42 satisfactory results so that the model can be taken for further analyses.
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49 *Findings of the Structural Model*

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51 The results of the structural model are depicted in figure 2. They demonstrate a strong
52
53 support for the conceptual model presented here and confirm hypothesis 1 for three out
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55 of four cases. A supportive layer of factors (layout, setup and quality) exists and fosters
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57 the implementation of a Kanban production system. The strongest link between the
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4 supportive layer and Kanban can be found in a production layout that emphasises a
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6 cellular layout of machine groupings and aims at smoothening the flow of material and
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8 products through production. Further significant support to Kanban systems is delivered
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10 by programs to shorten setup times. Of less importance is the quality focus on shop
11
12 floor level. Nevertheless, the relationship is statistically significant and promotes
13
14 Kanban implementation. Contrary to the theoretically assumed positive influence that
15
16 preventive maintenance should have on a Kanban production system, this relationship
17
18 cannot be found in the empirical data analyzed in this paper. The problems regarding
19
20 discriminant validity in terms of maintenance might be a reason for the fact that no
21
22 significant influence on Kanban could be found here since this factor is not clearly
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24 separated from the people oriented factors of the primary layer. Figure 2 gives an
25
26 overview of the empirical model:
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35 INSERT FIGURE 2

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38 Figure 2: Results of the structural model (t-values in brackets)

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41 With regard to the primary factors and their support to factors of the supportive layer
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43 the hypothesis 2a and 2b are confirmed by the model. All four proposed relationships
44
45 are highly significant and show high parameters. In order to implement a Kanban
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47 production system a strong focus should be put into upgrading and broadening of
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49 workforce skills and capabilities.
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55 *Linking TPS practices to performance*

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58 Based on the values of the described confirmatory factor analysis, a cluster analysis is
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60 performed in order to differentiate between plants that have implemented the practices

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4 of the Toyota Production System at a high, middle, or low degree. For the cluster
5 analysis Ward's method with the squared Euklidian distance has been conducted. The
6
7 grouping of the cluster analysis is confirmed by a discriminant analysis. The
8
9 discriminant analysis groups the plants with regard to the cluster analysis to a degree of
10 more than 90 percent. Accordingly, the three resulting clusters can be used for further
11 statistical analyses. In the following, the three clusters are examined in terms of the TPS
12 practices in order to check for consistency. The following figure depicts the mean
13 values for the factors representing the Toyota Production System.
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26 Figure 3: Comparison of means of the TPS-principles

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28 The mean values indicate the existence of three groups with different
29 implementation degrees of the TPS practices. The differences between the groups are on
30 a high significant level. In the following, the three groups are investigated concerning
31 their performance.
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38 The mean values show differences concerning several performance criteria on a
39 very significant level of $p < 0.05$. Especially, the plants which have implemented the
40 TPS practices to a high significant degree show higher average values in terms of cost
41 of manufacturing performance, product conformance, on time delivery, flexibility to
42 change volume, inventory turnover, and cycle time. Accordingly, the question whether
43 plants with a higher implementation degree of the Toyota Production System also show
44 a better performance can be affirmed. Only for the performance criteria fast delivery
45 and flexibility to change products mix no significant differences result. No significant
46 differences can be observed in terms of the other two clusters, although the cluster with
47 a medium implementation degree has almost always higher mean values in comparison
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4 with the cluster with the lowest implementation degree of the TPS. Figure 4 gives an
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6 overview of the mean values.
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13 Figure 4: Comparison of means of the performance criteria
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20 CONCLUSIONS

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23 In this paper, we examined the Toyota Production System empirically. The results show
24 that there exist differences between the plants participating at the “High Performance
25 Manufacturing”-project. The empirical analyses show that many manufacturers make
26 use of the Toyota Production System and adopt this approach to their production area in
27 order to “fit into their new suit”.
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36 Particularly, the analyses performed show that the training of workers has a
37 strong influence on the Toyota Production System supporting factors preventive
38 maintenance and quality, whereas multi-skilled workers have a strong influence on the
39 supportive factors process-oriented shop floor layout and short setup times (However, it
40 has to be noted that the measurement of the factor multi-skilling was not fully satisfying.
41 As expected from theory, the factors multi-skilling and training show a relatively high
42 correlation.). The statistical analysis also shows a relationship between the supportive
43 factors process-oriented shop floor layout, short setup times and quality, and the main
44 factor of the Toyota Production System: Kanban. Therefore, the model of the Toyota
45 Production System discussed in this paper has been proven valid with the exception of
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4 preventive maintenance (as potential reason for this the problem in terms of
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6 discriminant validity has already been mentioned.).
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10 Important conclusions can be drawn from the empirical analyses. First, skills
11 and training of the workers is the key for a successful implementation of the Toyota
12 Production System. The supportive layer with its practices such as short setup times,
13 layout, and quality is fulfilled by the actions of the workforce. Without the properly
14 trained and skilled workers these practices will stay a hollow shell and they will not
15 develop their full potential, which is again key for the core concept of the Toyota
16 Production System Kanban.
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26 Second, the supportive layer with quality, process-oriented layout, and short
27 setup times forms the infrastructure for Kanban. The proper function of Kanban relies
28 on the successful implementation of these supportive practices, since short setups,
29 excellent quality, and a process-flow oriented layout lead to small lot sizes and a short
30 reaction time. Surprisingly, maintenance has no significant influence on Kanban, which
31 was not suspected, since stable processes should be a prerequisite of Kanban. One
32 explanation could be that the companies questioned already have stable processes so
33 that the use of autonomous or preventive maintenance is regarded as no longer
34 important. A second explanation could be that many managers do not know about the
35 influence of maintenance on Kanban and since they lack maintenance implementation,
36 they do not fully deploy the advantages of Kanban, which leads to a higher number of
37 Kanban cards in process and subsequently to higher inventories.
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54 Thirdly, the combination of the two paragraphs leads to an important conclusion:
55 Since Kanban is the centre of the Toyota Production System and it is strongly
56 influenced by the supportive factors quality, setup times and shop floor layout, which
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4 are triggered by the training and skills of the workforce, the workers are the core
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6 element of the Toyota Production System and they make it a success or a failure.
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9 Another way of putting it is that quality, setup times and layout is the vehicle to get a
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11 functioning Toyota Production System, but the workforce is the driver.
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14 The fourth conclusion contains a very basic, but important result: The analyses
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16 prove that plants that have implemented the practices of the Toyota Production System
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18 more thoroughly than other factories, experience better results in the key performance
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20 metrics of production: cost, cycle time, quality, and flexibility. Especially, in terms of
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22 criteria for efficiency such as manufacturing cost, high inventory turnovers or short
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24 manufacturing cycle times the TPS practices play a crucial role.
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28 Note, that plants with a high implementation degree of the TPS practices neither
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30 show better performance in terms of fast delivery nor concerning the flexibility to
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32 change product mix. The reason for this result is quite intuitive. First, for a successful
33
34 implementation of Kanban, on-time deliveries are a necessary prerequisite as an
35
36 external factor of the supportive layer as well as an intended consequence of Kanban
37
38 itself. Short delivery times might be counterproductive in the sense that they are realized
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40 at the cost of a lower on-time delivery ratio: The shorter the delivery times are the more
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42 difficult it will be to deliver on-time. Second, stable processes are the foundation of
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44 Kanban in order to make this production system run efficiently. Hence, many changes
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46 in the product mix are not worthwhile because they would disturb the stability of the
47
48 underlying process.
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54 The four conclusions lead to the following managerial implications: A
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56 manufacturing company should focus on the workforce first, because they must be
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58 regarded as the key for success or failure. As the analyses shows the workforce gives
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4 life to the infrastructure, therefore focusing solely on TPS practices like quality, short
5 set up times etc. and neglecting the workforce, will not achieve the desired outcome, a
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9 powerful Kanban system that supports lean just-in-time production. Hence, create the
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11 “respect-for-human” system (Sugimori et al., 1977) as priority, since it empowers the
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13 infrastructure. Second, a manufacturer must implement the necessary infrastructure of
14
15 TPS practices in its manufacturing environment, since the infrastructure is the
16
17 prerequisite for a successful Kanban system. If there are TPS practices missing or only
18
19 weakly established, the management should start the implementation or improvement
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21 with the shop floor layout and setup times and then focus on quality, since the first
22
23 mentioned have a stronger impact on Kanban than quality. However, factory
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25 management should not neglect either one of the implication, since the analysis shows
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27 that the combination of the workforce and the supportive infrastructure is critical for the
28
29 success off a Kanban system or as it is stated above, setup times and layout is the
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31 vehicle to get a functioning Toyota Production System, but the workforce is the driver.
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37 Finally, the argument why a manufacturing company should take all this effort is quite
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39 simple: The analysis of the performance criteria cost, time, quality, and flexibility
40
41 shows that a thorough implementation of TPS practices leads to a superior performance
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43 in these key manufacturing metrics, which gives a company a competitive edge over its
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There are some research limitations that should be mentioned. Firstly, this study exclusively considers the automotive, electronics, and machinery industry. A generalization of the results might be critical since it cannot be ruled out that plants from other industries - not covered by the “High Performance Manufacturing” project - might show different results concerning the TPS.

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5 This study revealed interesting results concerning Kanban and its drivers for
6
7 implementation. However, there is still research needed in this area. It would be
8
9 favourable to include companies from countries other than the one participating in this
10
11 study. An international survey would give insights concerning the degree of
12
13 implementation of the TPS in other countries or could identify the impact of cultural
14
15 differences. Secondly, only respondents closely related to the production area such as
16
17 the Inventory Manager, Production Control Manager, and three Shop Floor Supervisors
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19 are asked for their estimations. A comparison of these estimations with respondents
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21 from other hierarchies, e.g. shop-floor workers, or other functional areas such as human
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23 resources, logistics, etc. would be interesting since such a study could show potential
24
25 distortions in terms of the perception of the advantageousness and importance of the
26
27 TPS. Thirdly, a longitudinal study might be interesting with respect to the diffusion of
28
29 the TPS. Such a survey would have the potential to identify certain development trends.
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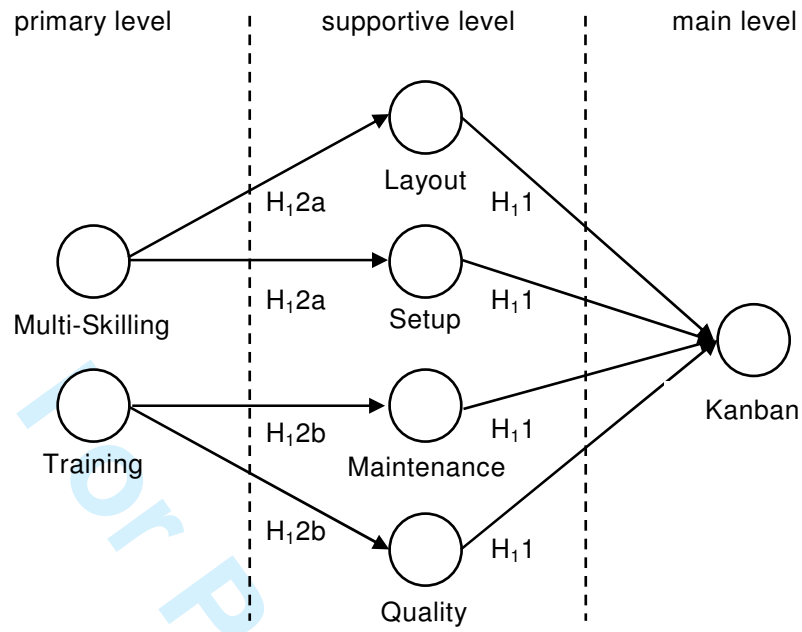


Figure 1

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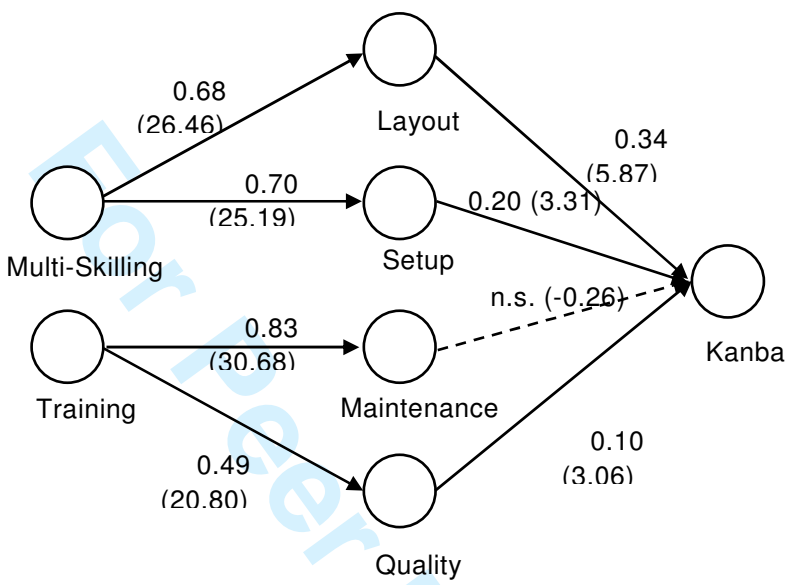


Figure 2

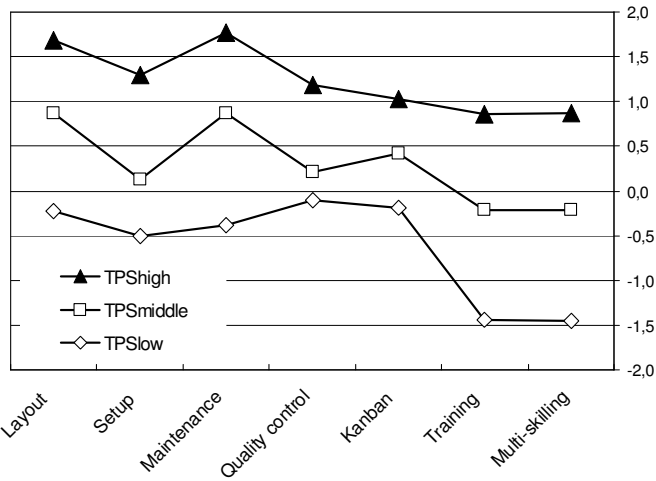


Figure 3

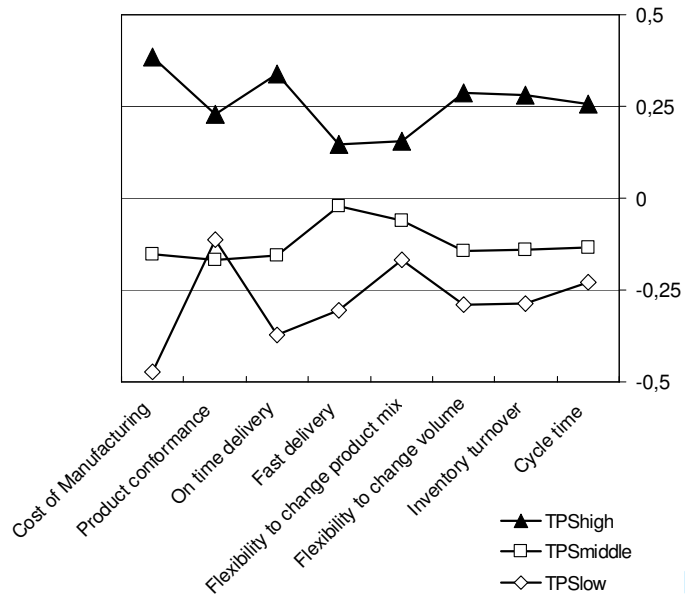


Figure 4

1. TPS level	2. Factor	3. Item	Cronbach's alpha (explained variance)	Factor loading
Elementary	KANBAN	Suppliers fill our kanban containers, rather than filling purchase orders	0.88 (0.64)	0.75
		Our suppliers deliver to us in kanban containers, without the use of separate packaging		0.85
		We use a kanban pull system for production control		0.76
		We use kanban squares, containers or signals for production control		0.83
Supportive	Layout	We have laid out the shop floor so that processes and machines are in close proximity to each other	0.86 (0.62)	0.78
		The layout of our shop floor facilitates low inventories and fast throughput		0.86
		Our processes are located close together, so that material handling and part storage are minimized		0.78
		We have located our machines to support JIT production flow		0.72
	Setup	We are aggressively working to lower setup times in our plant	0.82 (0.54)	0.72
		We have converted most of our setup time to external time, while the machine is running		0.70
		Our crews practice setups, in order to reduce the time required		0.69
		Our workers are trained to reduce setup time		0.83
	Maintenance	We upgrade inferior equipment, in order to prevent equipment problems	0.77 (0.47)	0.65
		We estimate the lifespan of our equipment, so that repair or replacement can be planned		0.64

		We use equipment diagnostic techniques to predict equipment lifespan		0.76
		Our production scheduling systems incorporate planned maintenance		0.68
	Quality	A large percent of the processes on the shop floor are currently under statistical quality control	0.90 (0.68)	0.82
		We make extensive use of statistical techniques to reduce variance in processes		0.94
		We use charts to determine whether our manufacturing processes are in control		0.65
		We monitor our processes using statistical process control		0.85
	Multi-skilling	Employees at this plant learn how to perform a variety of tasks	0.83 (0.34)	0.59
		Employees are cross-trained at this plant, so that they can fill in for others, if necessary		0.60
		Our employees regularly receive training to improve their skills		0.62
		Our employees are highly skilled, in this plant		0.52
Primary	Training	Our employees receive training to perform multiple tasks	0.89 (0.50)	0.66
		Our plant employees receive training and development in workplace skills, on a regular basis		0.76
		Management at this plant believes that continual training and upgrading of employee skills is important		0.64
		Our employees regularly receive training to improve their skills		0.76
All factor loadings are significant with $p < 0.01$				

Table 1

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	Factor correlations					
	Layout	Setup	Maintenance	Quality	Multi-skilling	Training
KANBAN	0.46	0.39	0.32	0.27	0.39	0.40
Layout	1.00	0.48	0.54	0.32	0.68	0.65
Setup		1.00	0.55	0.33	0.69	0.67
Maintenance			1.00	0.41	0.79	0.83
Quality				1.00	0.47	0.49
Multi-skilling					1.00	0.96
All correlations are significant with p<0.01						

Table 2

For Peer Review Only